EQUALIZER PERFORMANCE ENHANCEMENTS FOR BROADBAND
WIRELESS APPLICATIONS

5   **BACKGROUND OF THE INVENTION**

Field of the Invention

This invention relates to a home base modem system in a wireless communication system that provides telephone, data and Internet connectivity to a plurality of users.

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Description of Related Art

Several systems are currently in place for connecting computer users to one another and to the Internet. For example, many companies such as Cisco Systems, provide data routers that route data from personal computers and computer networks to

15   the Internet along conventional twisted pair wires and fiber optic lines. These same systems are also used to connect separate offices together in a wide area data network.

However, these systems suffer significant disadvantages because of the time and expense required to lay high capacity communications cables between each office. This process is time consuming and expensive. What is needed in the art is a high capacity

20   system that provides data links between offices, but does not require expensive communication cables to be installed.

Many types of current wireless communication systems facilitate two-way communication between a plurality of subscriber radio stations or subscriber units (either fixed or portable) and a fixed network infrastructure. Exemplary systems include

25   mobile cellular telephone systems, personal communication systems (PCS), and cordless telephones. The objective of these wireless communication systems is to provide communication channels on demand between the subscriber units and the home base in order to connect the subscriber unit with the fixed network infrastructure (usually a wired-line system). Several types of multiple access systems currently exist

for wirelessly transferring data between multiple sites. For example, wireless communication systems have typically used a Code Division Multiple Access (CDMA), Time Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA) type system to facilitate the exchange of information between two users.

5   These access schemes are well known in the art.

Often in these wireless communication systems a modem is used for modulating and demodulating the information that is exchanged between users. Inside the modem circuit an equalizer is employed to correct distortions either in the wireless channel or fix imperfections in the analog circuitry. A novel equalizer with enhancements to

10   improve performance especially using higher order QAM modulation is described herein.

SUMMARY OF THE INVENTION

In one embodiment, the method comprises demodulating a data stream

15   transmitted between remote sites and a home base using stored parameters for each remote site comprising receiving data from a current remote site at a home base, retrieving a parameter associated with a next remote site from a memory, storing the retrieved parameter for the next remote site in a first buffer, storing a second parameter associated with the current remote site into the memory, determining the initial phase

20   and gain values for the next remote site based on the retrieved parameter, receiving data from the next remote site at the home base, and demodulating the data received from the next remote site using the determined initial phase and gain values.

In one embodiment, the method comprises compensating for gain droop in a modem which stores equalizer coefficients across data bursts between a remote site and

25   a home base comprising receiving channel data values from an equalizer, calculating the gain for the equalizer based on the received channel data values, and scaling the input to the equalizer to achieve a value of 1 based on the calculated gain.

In one embodiment, the method comprises minimizing errors caused by adapting equalizer coefficients for each data burst from a remote site to a home base comprising

retrieving a first equalizer coefficient for a current remote site, demodulating a data burst from the current remote site, determining the S/N ratio for the received burst, determining the error rate from the demodulated burst, comparing the determined S/N ratio and error rate to defined thresholds, and updating the first equalizer coefficient based on the comparisons.

In one embodiment, the method comprises improving the convergence of an equalizer in a multi-modulation modem using a two part preamble comprising defining a first part of a preamble with a lower order section, wherein the lower order section is transmitted using QPSK modulation, defining a second part of the preamble with a higher order section, wherein the higher order section is transmitted using QAM 64 modulation, transmitting both the first and second parts of the preamble, receiving the transmitted preamble, and converging the equalizer based on the received preamble.

In one embodiment, the method comprises providing a soft reset to a modem comprising generating an interrupt to the modem, halting the modem interface, setting a reset bit, flushing a buffer, realigning the buffer, reprogramming the buffer, and restarting the interface.

In one embodiment, the method comprises determining an adaptation factor for an equalizer based on the expected modulation type of an incoming burst transmission comprising calculating channel characteristics and metrics for a first burst transmission from a remote site, comparing the channel characteristics and metrics, determining an expected modulation type for a second burst transmission from the remote site based on the comparison, selecting an adaptation factor based on the expected modulation type, and applying the selected adaptation factor to the second burst transmission.

In one embodiment, the method comprises correcting the phase shift caused by the storage of tap values after each incoming burst transmission comprising determining an angle of correction based on correlating the input and output of the equalizer and applying the determined angle of correction to the incoming signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of one embodiment of a modem.

FIG. 2 is a block diagram of one embodiment of a receiver module for the modem.

FIG. 3 is a block diagram of one embodiment of a Digital Equalization module from Figure 2.

FIG. 4 is a block diagram of one embodiment of the gain droop compensation module shown in Figure 3.

FIG. 5 illustrates a comparison of 64QAM Error Histograms using a two-type preamble with 2000FT Cable.

FIG. 6 is a zoomed view of Figure 5.

FIG. 7 gives the BER and the probability of the first RS word using the two-type preamble and different cable length.

FIG. 8 is a block diagram of one embodiment of a tap update circuit from the digital equalization module shown in Figure 3.

FIG. 9 is a block diagram of one embodiment of a system for estimating the phase shift caused by the digital equalization module shown in Figure 3.

FIG. 10 is an illustration of one state of the digital equalization module shown in Figure 3.

FIG. 11 is an internal block diagram of a parameter storage module.

FIG. 12 is a signal flow diagram of the process performed by the parameter storage module in processing uplink bursts.

FIG. 13 is a block diagram of one embodiment of a Digital Equalization Parameter Storage and Recovery system.

FIG. 14 is a flow chart illustrating the process performed by the error recovery module 968 shown in Figure 13.

Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION OF THE INVENTION

Throughout this description, the embodiment and examples shown should be considered as exemplars, rather than as limitations on the present invention.

As shown in Figure 1, one embodiment of a modem 100 includes a receiver
5 module 102 and a transmitter module 104. The transmitter module 104 receives digital data from a communications processor (not shown) and converts the data to an appropriately modulated analog carrier signal, for example, quadrature amplitude modulation (QAM) or quadrature phase shift keying modulation. The analog signal may or may not be up converted to a carrier frequency prior to transmission. The
10 receiver module 102 demodulates an incoming modulated carrier signal and converts it back to its original digital form. A similar or identical modem may be used as the other end of a communication link.

One embodiment of the receiver module 102 is illustrated in Figure 2. The receiver module 102 includes a conditioning circuit module 908, a digital equalization
15 module 930, a digital phase-locked loop module 950, a decode/decryption module 959, a parameter storage memory module 933, an initial gain adjust module 920, an adaptive modulation module 980, a signal to noise ratio ("SNR") calculator 935, and an acquisition, tracking, and modulation control module 918.

One embodiment of the conditioning circuit module 908 includes an analog to
20 digital converter 910, a digital quadrature mixer 912, a matched filter 914, a correlation timing recovery module 916, an automatic frequency control module 971, an automatic gain control module 970, a dual digital to analog converter 924, and a voltage controlled oscillator 922. The down-converted signal from the Intermediate Frequency (IF) is sampled by the digital to analog converter 910 to produce a digital output that is
25 provided to the digital quadrature mixer 912. In one embodiment, the digital quadrature mixer 912 splits the received signal into it's quadrature components and translates the signal, for example, from a 20MHz IF, to baseband.

The matched filter module 914 maximizes the signal to noise ratio by "matching" the frequency response of the receiver module 102 to the signal generated at

the transmitter module 104. In one embodiment, the matched filter module 914 also rejects adjacent and unwanted signals that could be generated by other transmitters in the system, or interfering spurs generated by imperfections in the analog circuitry.

Still referring to Figure 2, the filtered output from the matched filter 914 is then driven into the correlation timing recovery module 916.

The acquisition, tracking and modulation control module 918 provides control information, such as the modulation type or format of data, for the received burst to the correlation timing recovery module 916. The acquisition, tracking and modulation control module 918 performs acquisition tracking and modulation control. Multiple data signals are fed to the acquisition, tracking and modulation control module 918 to control the high level operations of the receiver module 102.

In one embodiment, the correlation timing recovery module 916 aligns the symbol timing to the samples fed to the digital equalization 930, and calculates the initial gain and phase offset so that the digital equalization 930 can quickly perform channel inversion and correct any residual distortion due to inaccuracies in the phase and timing estimations. In one embodiment, the correlation timing recovery module 916 calculates the sample timing error by performing correlation between the received preamble with a copy of the expected preamble. The output of the correlation timing recovery module 916 is fed to an interpolation circuit, which further refines the received sample timing offset. After the interpolation filter of the correlated preamble sequence, an accurate calculation, for example, to 1/16 symbol time is fed to a polyphase filter which manipulates the received samples to correct for the timing. Even though the samples may be aligned to the correct timing, the constellation may be rotated relative to a phase of zero degrees. The correlation timing recovery module 916 will calculate this angle and feed it to the numerically controlled oscillator 952 so that the timing and phase are corrected enough for the digital equalization 930 to quickly fix any further distortions.

In one embodiment, the correlation timing recovery module 916 calculates the received gain offset. The gain is adjusted once based on the detected energy in the

preamble correlator. Gain is adjusted digitally by feeding a value to the initial gain adjust 920. The initial gain adjust 920 maps the received quadrature symbols to the proper level before they are equalized by the equalizer. The initial gain is calculated by the correlation timing recovery module 916. The correlation timing recovery module

5   916 performs frequency acquisition and automatic frequency correction (AFC) in combination with AFC 971.

The modem 135 may be equipped with a process for providing soft resets. A reset signal, while the modem 135 is in transmit mode, may occur in several instances. For example, during uplink transmission, a software module may be too slow in sending

10   data to the modem 135, as may occur if the data is modulated using quadrature amplitude modulation 64. In such a case, the limited data received by the modem 135 may cause an interrupt to be generated. The modem 135 then halts the transmit interface and sets a transmit-reset bit. The modem 135 then flushes, realigns, and reprograms the necessary buffers. Once this process is completed, the modem 135

15   restarts the transmit interface, completing the reset operation.

Similarly, a reset signal may occur while the modem 135 is in a receive mode. For example, the modem 135 may receive only bad cyclic redundancy check packets. In such a case, the modem 135 halts the receive interface and sets a receive-reset bit. The modem 135 then flushes and realigns the receive buffers and reprograms the

20   necessary buffers. The modem 135 then restarts the receive interface, thus completing the reset operation.

One embodiment of the digital equalization module 930, illustrated in Figures 2 and 3, includes a gain droop compensation module 941, an adaptive filter module 932, a feed forward tap update module 934, a decision feedback module 936, a DFE adaptation

25   module 938, and an EQ Error calculator module 940.

The gain droop compensation loop 941 is located between the output of the correlation timing recovery module 916 and the input of the digital equalization module 930. The gain droop compensation loop 941 accounts for any gain variations due to radio droop in an outdoor unit (not shown) forcing a gain factor which is a ratio to the

calculated gain observed in the digital equalization module 930. In one embodiment, this gain ratio is kept to unity.

A detailed description of the gain droop compensation loop 941 is shown in Figure 4. The outputs of the digital equalization module 930, for example, taps 4 and 5, are multiplied by 0.625 and 1, respectively. In one embodiment, the values of taps 4 and 5 are received after every symbol. This value is then summed with the resulting value being subtracted from nominal '1'. In one embodiment, this final value is 253. An adaptation factor (μ in Figure 4), is then applied to this final value which is used to increment or decrement a gain constant similar to the adaptive filter 932 described in the digital equalization module 930. The gain constant multiplies the input signal value to provide a gain to the digital equalization module 930 to be '1'. A gain of '1' enhances the stability of the digital equalization module 930. In one embodiment, the gain constant is reset every burst wherein at the end of each burst, the digital equalization module 930 has a gain of '1.' In one embodiment where the digital equalization module 930 has a gain of '1', the gain estimation module 921 of the Correlation Timing Recovery module 916 assumes that the digital equalization module 930 starts with an initial gain of '1.'

The digital equalization module 930 corrects any signal impairments due to multipath reception or distortion caused by imperfections in the analog receiver circuits. In the modem, the transmitter module 104 sends a known training sequence before the burst so that the digital equalization module 930 can learn what the distortion is and undo it before the data arrives. The length of time the digital equalization module 930 is allowed to observe the impairments must be balanced against the amount of bandwidth that is wasted sending the training sequences over the channel. The digital equalization module 930 decimates the received data from the correlation timing recovery module 916 into a one-sample-per-symbol complex signal.

Within the equalizer, the acquisition, tracking and modulation control module 918 ascertains the next remote site's address and its expected modulation type based on comparisons of channel characteristics and metrics. In one embodiment, a reed

solomon decoder module 962, illustrated as a component of the decode/decryption module 959, and the SNR calculator 935 calculate these channel characteristics and metrics. Once calculated, the adaptive modulation algorithm 980 compares the calculated channel characteristics and metrics and provides the information to the higher layers of the communication system. The higher layers then define what the expected modulation format is for the received burst from the next remote site. The higher layers convey these results to the acquisition, tracking and modulation control module 918. Depending on what modulation is expected, the digital equalizer uses different adaptation factors (μ's) for each received burst. Selecting an adaptation factor that is optimized for the received modulation type improves the performance of the modem by increasing the probability that the parameters stored in the parameter memory storage module 933 at the end of the processed burst will be valid.

Returning to Figure 3, the digital equalization module 930 is composed of two sections: a feed-forward section and a feedback section. The feed-forward section is composed of an adaptive filter 932 and a feed forward tap update module 934. In one embodiment, the feed forward tap update 934 adapts the coefficients for the feed-forward section of the digital equalization module 930 based on the Least Mean Squares (LMS) module. This is a gradient descent-based feed forward tap update 934, which converges to a local minima by forcing the output of the adaptive filter 932 to a known state or a training sequence. The tap update formula for the gradient LMS module is given by:

$$W(k) = W(k-1) - \mu \nabla J$$

W(k) is the value of the new coefficient. W(k-1) is the value of the coefficient at the last instant in time. M is the step-size variable, and ∇J is the complex gradient of the system. The gradient for each dimension (tap) C for time k is given by:

$$\nabla_{Ck} J = -2x(k-c)\varepsilon^*(k)$$

The equation for the error of the equalizer at time k is given by:

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$$\varepsilon(k) = d(k) - W(k)^H X(k)$$

Where: $\varepsilon =$ the error between the desired signal (training or decisions) and the filtered signal complex (I and Q channels) signal X

5          $d =$ The desired signal from a training sequence or feedback decisions

$W =$ The complex vector of the filter taps

$X =$ The input signal.

10   The preambles not only are used for timing recovery but are also used to converge the digital equalization module 930. The preambles are chosen so that home bases in adjacent sectors do not interfere with one another and that close remote sites will not interfere with one another. There is a different Preamble for uplink, and a different preamble for downlink. There are four types of uplink preambles (1) 15   Unscheduled registration bursts, (2) scheduled 16-QAM bursts, (3) scheduled QPSK bursts, and (4) scheduled 64-QAM bursts. The hardware is designed to detect which preamble is being transmitted and decode the burst using the correct preamble. The preamble for the higher orders are subdivided into a QPSK section, and a higher order section allowing faster convergence in the digital equalization module 930 which is 20   critical in burst modem design and at the same time can be used for symbol timing recovery.

1) The preamble is a mixture of both End Points and Middle QAM-64 Points

2) The Preamble is chosen for Uplink and Downlink Differently so that Adjacent home bases will not detect each other as transmitting remote sites

25   Figure 5 illustrates a comparison of QAM-64 Error Histograms using a two-type preamble with 2000FT Cable. Figure 6 is a zoomed view of Figure 5. Figure 7 gives the BER and the probability of the first reed-solomon ("RS") word using the two-type preamble and different cable length. For example, if the digital equalization module

930 is pre compensate over 1000FT cable using Preamble type 2 we get the following results: BER of 5.81e-4 and an RS Error Rate of 1.5e-5.

Figure 8 illustrates an embodiment of a feed forward tap update module 934 (illustrated in Figure 3). Upon initial acquisition, remote sites Reset, or remote sites

5 register, the taps are reset such that the center tap is set to '1' and the other taps are reset to '0'. If the taps have been initialized and adapted in past history, the tap update circuit receives a stored coefficient from the medium access control processor. The taps are updated to their new value by converging with either a training sequence (preamble) or the decision feedback 936 data from the decision device 958. After remote site

10 processing, the medium access control processor is responsible for storing the updated coefficients to a remote site database.

Preferably, the digital equalization module 930 coefficients are initialized to take advantage of the knowledge gained during the previous bursts. Initialization relieves some of the concerns related to the digital equalization module 930 convergence time.

15 One approach is to initialize the taps with the values from the end of the previous burst. However, this results in the digital equalization module 930 possibly having adapted to correct a phase shift (e.g., one introduced by phase noise or frequency offset) during the previous burst. At the beginning of the new burst, the correlation timing recovery module 916 re-calculates the initial phase and sets the symbol rotator to properly rotate

20 the signal. This calculation assumes that the digital equalization module 930 does not introduce any overall phase rotation.

A method for estimating the phase shift caused by the digital equalization module 930 and the mathematical basis will now be described.

Figure 9 illustrates a simplified block diagram of the system. For purposes of

25 simplicity, the transmit and matched filters are assumed to have 2 samples per symbol. The odd samples of x are assumed to be zero (i.e., the pulse shape filter does the interpolation from 1 sample/symbol to 2 samples/symbol). The digital equalization module 930 is assumed to be T/2 spaced.

If the channel is assumed to have no intersymbol interference, and the cascade of the transmit and matched filters is assumed to create an ideal Nyquist filter, then the even values of y are simply phase-shifted versions of the transmitted symbols, x. This is true because the even values of h are zero (except for h_0). If the digital equalization module 930 is also assumed to do a decimation (as our implementation does), then the digital equalization module 930 outputs a value when the even values of y line up with the main tap. To determine the phase shift induced by the digital equalization module 930, the correlation between the input and output of the digital equalization module 930 at zero lag is desired. This is illustrated by the calculations described below.

The output of the expectation operator for each tap is calculated individually (denoted it as r_m):

$$
\begin{aligned}
r_2 &= E\{c_2 y_{k+2} \bar{y}_k\} \\
&= c_2 E\{x_{n+2} e^{j\theta} \bar{x}_n e^{-j\theta}\} \\
&= c_2 E\{x_{n+2} \bar{x}_n\}
\end{aligned}
$$

but transmit symbols (x) are uncorrelated, so

$$
= c_2 0 = 0
$$

$$
\begin{aligned}
r_1 &= E\{c_1 y_{k+1} \bar{y}_k\} \\
&= c_1 E\left\{e^{j\theta} \bar{x}_k e^{-j\theta} \sum_{m=-2N}^{2N} x_{k+1-m} h_m\right\} \\
&= c_1 E\{\ldots + h_{-2} \bar{x}_k x_{k+3} + h_{-1} \bar{x}_k x_{k+2} + h_0 \bar{x}_k x_{k+1} + h_1 \bar{x}_k x_k + \ldots\} \\
&= c_1 h_1 E\{|x_k|^2\}
\end{aligned}
$$

$$r_0 = E\{c_0 y_k \bar{y}_k\}$$
$$= c_0 E\{x_k e^{j\theta} \bar{x}_k e^{-j\theta}\}$$
$$= c_0 h_0 E\{|x_k|^2\}$$

$$r_{-1} = E\{c_{-1} y_{k-1} \bar{y}_k\}$$
$$= c_{-1} E\left\{e^{j\theta} \bar{x}_k e^{-j\theta} \sum_{m=-2N}^{2N} x_{k-1-m} h_m\right\}$$
$$= c_{-1} E\{\ldots + h_{-2} \bar{x}_k x_{k+1} + h_{-1} \bar{x}_k x_k + h_0 \bar{x}_k x_{k-1} + h_1 \bar{x}_k x_{k-2} + \ldots\}$$
$$= c_{-1} h_{-1} E\{|x_k|^2\}$$

$$r_{-2} = E\{c_{-2} y_{k-2} \bar{y}_k\}$$
$$= c_{-2} E\{x_{n-2} e^{j\theta} \bar{x}_n e^{-j\theta}\}$$
$$= c_{-2} E\{x_{n-2} \bar{x}_n\}$$
$$= c_{-2} 0 = 0$$

Summing all the contributors to the correlation, only those from the main tap and the two adjacent to the main tap are non-zero:

$$r = r_{-1} + r_0 + r_{+1}$$
$$= E\{|x_k|^2\} \cdot (c_{-1} h_{-1} + c_0 h_0 + c_1 h_1)$$

Calculating for the angle of the correlation value:

$$\phi_{eq} = angle\left(c_{-1} h_{-1} + c_0 h_0 + c_1 h_1\right)$$

for raised cosine filter,

with α of 0.25

$$\phi_{eq} = angle\left(0.627 c_{-1} + c_0 + 0.627 c_1\right)$$

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A Mathcad simulation has been used to check the results shown above. With no timing error, the module shown above has been verified to be accurate. Although timing error was not included in the analysis above, the Mathcad simulation has shown that with reasonable timing error (e.g., T/8), the errors in the method shown above are very small (<0.3°).

One embodiment of the adaptation module 938 in the digital equalization module 930 (illustrated in Figures 2 and 3) uses a T/2 feed-forward filter, followed by a T-spaced decision feedback section. If the correct decisions are assumed to have been made, the adaptation module 938 can be illustrated as shown in Figure 10.

By calculating the correlation as described above with reference to Figure 9, the angle of the correlation is arrived at as follows:

$$\phi_{eq} = angle(c_0 h_0 + c_1 h_1)$$
$$\text{for raised cosine filter,}$$
$$\text{with } \alpha \text{ of } 0.25$$
$$\phi_{eq} = angle(c_0 + 0.627 c_1)$$

If the channel has non-zero intersymbol interference, the above descriptions can be characterized as approximately true. Intersymbol interference will change the weighting factor for the two taps adjacent to the main tap, and the contribution of the other taps to the digital equalization module 930 phase shift becomes non-zero. Simulation results have shown that the adaptive module 938 described above is effective with all intermediate frequency filter models. Thus, since the magnitude of the intersymbol interference is typically small, it can be neglected.

As illustrated in Figure 2, the output of the digital equalization module 930 is fed to the digital phase-locked loop module 950. One embodiment of the digital phase-locked loop module 950 includes a numerically controlled oscillator 952, a loop filter module 954, a phase error module 956, and a decision device 958. The decision device

958 receives the signal from the digital equalization module 930 and maps each complex signal pair into a sliced constellation symbol.

The digital phase-locked loop 950 uses the input and output of the decision device 958 to continuously correct any phase error using hardware complex multipliers (or rotators) 953. The output of the decision device 958 is also fed back into the decision feedback module 936 of the digital equalization module 930, where it is used to adapt the equalizer coefficients.

Figure 2 illustrates a parameter storage module 933. The parameter storage module 933 contains channel characteristics, in the form of taps, corresponding to each remote site. In one embodiment, each remote site has different tap values, each of which corresponds to a recent communication parameter by the remote site. Since each remote site has different channel characteristic, each remote site's tap values must be stored and retrieved independently. The digital equalization module 930 receives, from the parameter storage module 933, the tap values corresponding to the remote site that is presently sending an uplink burst to the modem 135. Once received, the digital equalization module 930 sets the correct channel characteristics for the incoming burst from the remote site which helps the modem 135 perform by keeping estimates of the channel characteristics for each transmission from each remote site. In one embodiment, the acquisition, tracking and modulation control module 918 generates an index of remote sites and their associated tap values to expedite their retrieval from the parameter storage module 933. After receiving a burst from one of the remote sites, the parameter storage module 933 updates the stored tap values for that remote site.

Figure 12 is a signal flow diagram of the process performed by the parameter storage module 933, illustrated in Figure 2, in processing uplink bursts after the correlation timing recovery module 916 but before the decision device module 958. The process stores and retrieves parameters to/from memory when processing bursts from different remote sites at the home base receiver module 102.

The process begins at a start state 2540. Next at a state 2542 the home base receiver retrieves a remote site number from the acquisition, tracking and modulation

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control 918. Next, at a state 2544, the parameter storage module 933 retrieves parameters for this (next) remote site, for example, the equalizer taps from the previous burst. Next, at a state 2546, the parameter storage module 933 retrieves parameters for this (next) remote site, for example, the attenuation levels. In one embodiment, these parameters are stored in a first temporary buffer. Flow proceeds to a state 2550 where the parameter storage module 933 waits until the current burst is completed. Flow continues to a decision state 2552 where the process determines whether the current burst is completed. If the home base receiver is currently processing an uplink burst, the parameter storage module 933 waits until the current burst is finished. In one embodiment, the acquisition, tracking and modulation control module 918 informs the parameter storage module 933 that the current burst is finished. If the current burst is not completed, the process loops back to state 2550. Otherwise, if the current burst is completed, flow proceeds to a state 2554 where the retrieved parameters for the current remote site are stored into a second temporary buffer.

In one embodiment, the decision whether to store the parameters depends on the state of the processed error metrics calculated by the error recovery module 968. For example, if the error thresholds are not exceeded, the parameter storage module 933 stores the retrieved parameters. Next at a state 2556, the attenuation and EQ taps for the current remote site retrieved from the feed forward tap update 934 and DFE adaptive algorithm 938 are stored into a second temporary buffer. Flow proceeds to a state 2558 where the parameters from the first temporary buffer for the next remote site burst are transferred to the feed forward tap update 934 and DFE adaptive algorithm 938 modules.

Continuing to a state 2560, the modem 100 waits for the next remote site burst to arrive. Also at state 2560, the parameter storage module 933 writes the parameters from the second temporary buffer to the parameter storage memory 933. Next at a decision state 2562, the correlation timing recovery module 916 sends a message to the modem processing blocks when the next remote site burst is present. If a burst is not present, flow loops back to state 2560 as discussed above. Otherwise, if the next remote

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site burst is present, the process continues to a state 2564 where the correlation timing recovery module 916 calculates the initial phase and gain of the burst. Next at a state 2566, the correlation timing recovery module 916 applies the gain and phase to the initial gain adjust module 920 and 952 respectfully. Next at a state 2568 the parameter storage memory 933 calculates the Equalizer phase offset from the retrieved EQ taps and then applies this offset to the numerically controlled oscillator 952. Next at a state 2570, the burst is ready to be processed by the receive chain of the home base receiver module 102. Flow then proceeds to an end state 2572. In one embodiment, this process is performed for each received uplink burst.

To increase the likelihood that the stored channel parameters, or taps, will be valid for an incoming burst, factors, such as, symbol timing, interpolator timing, end of a burst gain value, and any phase offset generated by the digital equalization module 930, may be optimized. In one embodiment, locking the symbol timing within 1/8 symbol, locking the timing interpolator, providing a nominal gain of '1' for the taps at the end of a burst, and compensating for any phase offset generated by the digital equalization module 930 at the beginning of the following burst are done to increase the likelihood that an incoming burst will be recognized and found valid.

Figure 13 illustrates a Digital Equalization Parameter Storage and Recovery system. The Digital Equalization Parameter Storage and Recovery system includes the acquisition, tracking, and modulation control module 918, the digital equalization module 930, the parameter storage memory module 933, an error recovery module 968, the reed solomon decoder module 962, and the SNR calculator 935. In one embodiment, the SNR calculator 935 calculates the mean square error between the received symbol and the expected optimal symbol. By accumulating and averaging these calculations, an accurate measurement of the noise or interference of the system is measured. For example, when the SNR is high, the system can operate at a high order of modulation, say QAM-64. If the SNR is Low, the system must operate at a more robust modulation scheme such as QPSK. The output of the SNR calculator 935 is fed to the DFE adaptive modulation algorithm 938, which based on particular SNRs will

feed the acquisition, tracking and modulation control module 918 to specify which modulation scheme is optimal for the current channel characteristics.

The reed solomon decoder module 962 calculates the number of errors in a stream of 300-bits to measure the decode error rate. At the end of a burst from a remote

5   site, both of these calculated error values are then compared to threshold values by the error recovery module 968. If either of the calculated values exceed the threshold values, the error recovery module 968 does not update the stored channel parameters, or taps, in the parameter storage memory 933 for that remote site. In one embodiment, the stored channel parameters in the parameter storage memory 933 are reset when the

10   threshold is exceeded. In another embodiment, the stored channel parameters are replaced with zeros if the calculated values exceed the threshold values. If the threshold values are not exceeded, the new calculated channel parameters are stored in the parameter storage memory 933. These new channel parameters are available to the digital equalization module 930 to set the correct channel characteristics for the next

15   incoming burst from the remote site. Thus, the Digital Equalization Parameter Storage and Recovery system provides a recovery system should a catastrophic channel disruption occur.

Figure 14 illustrates the Digital Equalization Parameter Storage and Recovery process. The process begins at a start state 2900 and continues to a state 2902 where the

20   set of stored channel parameters associated with the transmitting remote site is retrieved. Next, at a decision state 2904, a determination is made as to whether a burst the remote site is being received. If a burst is not received, the process loops back to decision state 2904 until a burst is received. If a burst is received, the process moves to a state 2906 where the incoming burst is demodulated. At a next state 2908, the SNR

25   calculator 935 calculates the noise of the demodulated signal. Continuing to a state 2910, the error in the decoded signal is calculated by the reed solomon decoder module 962. Next at a decision state 2912, if the received burst is not at an end, flow continues to state 2906 as discussed above. Returning to decision state 2912, if the received burst is at an end, flow continues to a decision state 2914 to determine if the calculated noise

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from state 2908 exceeds a threshold value. If the calculated noise exceeds the threshold value, the process proceeds to a state 2916 where the current channel characteristics are invalidated. Flow then ends at an end state 2918.

Returning to decision state 2914, if the calculated noise does not exceed the noise threshold, flow moves to a decision state 2920 to determine if the calculated error in the decode signal exceeds the decode error threshold. If the decode error exceeds the threshold, the process continues to state 2916 as described above. Otherwise, if the calculated error in the decode signal does not exceed the decode threshold, the process moves to a state 2922 where the channel characteristics for the remote site burst are stored in the parameter storage memory 933. Flow then proceeds to the end state 2918.

In downlink communication, the equalization and channel estimation is simpler than in uplink communication. In the downlink direction, immediately after the training sequence is sent, data follows in a QPSK-modulation format. In the uplink direction, on the other hand, a higher-order modulation immediately follows the training sequence, worst case being QAM-64 modulation. In the downlink direction, the probability of making a bit error due to the equalizer not fully undoing the signal impairments is low since the Euclidean distance of received symbols for a QPSK constellation is much greater than the Euclidean distance of symbols for a QAM-64 constellation.

Preambles are not only chosen to converge the digital equalization module 930, but also used for timing recovery. Preambles are chosen such that uplink communication and downlink communication do not interfere with each other. The preamble structure is split into two sections. For the downlink preamble and the uplink-unscheduled preambles, a QPSK portion is repeated twice so that when the received signal is correlated with the local copy, a low probability of preamble false detection will occur when trying to acquire the downlink or when demodulating an unscheduled uplink burst. The receiver module 102 correlator followed by an interpolator filter bank is used to recover the timing by comparing the energy.

In one embodiment, the above noted techniques are used in combination by the modem 100 to perform higher order modulation techniques, for example, QAM 64.

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These techniques include performing the initial phase calculation on the incoming burst, performing droop compensation, performing a phase calculation on the stored taps, and storing channel characteristics, or taps, after each burst. These techniques are further combined with a method of performing symbol clock synchronization as described in

5   U.S. patent application _____, filed March 20, 2001 and entitled "SYNCHRONIZING CLOCKS ACROSS A COMMUNICATION LINK" which is hereby incorporated by reference. The combination of these techniques enhances the operation of the modem 100 when performing QAM 64 modulation.

Aspects of the present invention have been disclosed in one or more exemplary

10   embodiments. These embodiments are not to be construed as limiting, but rather as showing a way to practice the invention. The scope of the invention is defined by the claims which follow.